(54) Title: MULTI-CHANNEL AUDIO SURROUND SYSTEM
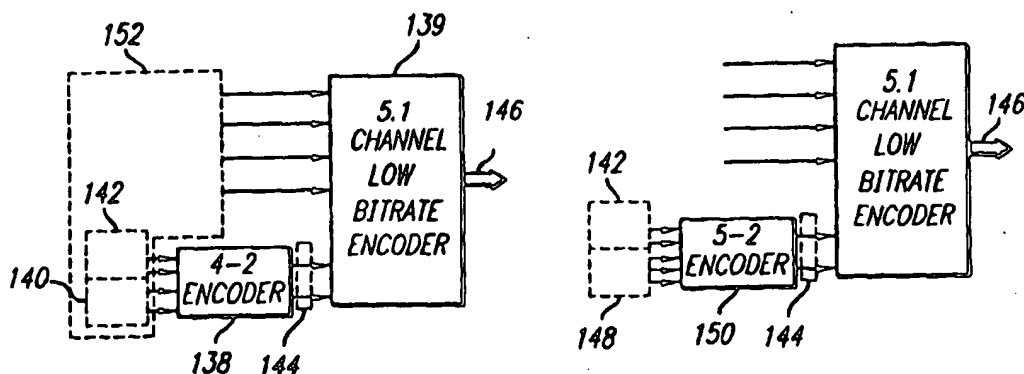
(57) Abstract

    The present invention provides a technique for adding channels of sound to multi-channel digital audio recording format, including but not limited to 5.1 channel formats. The currently preferred embodiment is applied to surround channels, but can be extended to front or other channel configurations. Additional applications may include motion picture soundtracks, multi-channel music, digital television, home video, etc. Multiple layers of matrix encoders and decoders may be used to add, record, recover and reproduce additional channels of recorded sound. For example, an audio surround system according to the present invention may use a layer of matrix encoders in addition to the conventional compression layer to encode three or more channels of surround audio into the two channels normally reserved for rear surround signals in a conventionally compressed 5.1 channel digital audio surround system. Thus the three surround channels would be double compressed. A layer of matrix decoders in addition to the conventional decompression layer may be used to decode the three channels of surround audio from the two channels normally reserved for rear surround signals in a conventionally compressed 5.1 channel digital audio surround system.

# MULTI-CHANNEL AUDIO SURROUND SYSTEM

5                    Background of the Invention

1. Field of the Invention:

This invention relates to multi-channel audio systems, and
more specifically to audio surround systems encoding and
10   decoding 6.1 or more channels of surround audio.

2. Description of the Prior Art:

Today's state-of-the-art motion picture soundtracks are
digitally recorded 5.1 channel formats.  These 5.1 channels are
recorded on the film area or on separate media synchronized with
15   the film.  Special digital coding techniques are used to
maximize the recording quality for the available digital bit
rate and transmission bandwidth.

Conventional 5.1 channels are generally reproduced as:

1) Three front channels produced by loudspeakers
20   typically placed behind acoustically transmissive
picture screens, to the left, right, and center of
screen area. Said loudspeakers are typically single
point source two-way or three-way full range systems.

2) Two surround channels typically placed along
25   the left and right walls of the auditorium. Said
surround channels are typically reproduced through
arrays of loudspeakers in a horizontal line at a height
above the audience.

3) A low frequency effects channel ($L_{fe}$, the 0.1
30   channel – 0.1 of the Bandwidth) reproduced by one or
more loudspeakers generally referred to as "subwoofers"
placed in the vicinity of the picture screen.

Most 5.1 channel recording/reproduction systems use three
front channels for placement of sounds between the left and
35   right edge of the picture screen as well as two surround
channels placed to the left or right side of the audience

seating area. Some formats generate up to 7.1 channels and provide 2 additional front loudspeakers which are generally placed in "half-left" and "half-right" locations.

5    A limitation of conventional audio surround systems is the difficulty in placing sounds to the rear of the auditorium. To do so generally requires extra loudspeaker systems placed in the rear of the auditorium, fed by added signals recorded in the soundtrack.

10    Recording the extra surround channels can be achieved by digitally coding added tracks. This will involve an increase in bitrate bandwidth and place additional demands upon the scarce real-estate of the recording medium (film print or digital storage) In many cases the newly augmented channel recording schemes would require modifications of coding algorithms or re-

15    assignment of recorded bit streams. This could lead to potential compatibility problems with existing coders and decoders already in the field, and potentially also to increasing costs of development and implementation.

What is needed is a technique if providing additional audio

20    surround channels that is compatible with existing audio surround implementations and current recording media bandwidth limitations.


## Summary of the Invention

25    The present invention provides a technique for adding channels of sound to multi-channel digital audio recording format, including but not limited to 5.1 channel formats. The currently preferred embodiment is applied to surround channels, but can be extended to front or other channel configurations.

30    Additional applications may include motion picture soundtracks, multi-channel music, digital television, home video, etc.

In a first aspect of the present invention multiple layers of matrix encoders and decoders are used to add, record, recover and reproduce additional channels of recorded sound. For

example, an audio surround system according to the present

invention may use a layer of matrix encoders in addition to the

conventional compression layer to encode three or more channels

of surround audio into the two channels normally reserved for

5    rear surround signals in a conventionally compressed 5.1 channel

digital audio surround system.  Thus the three surround channels

would be double compressed.  A layer of matrix decoders in

addition to the conventional decompression layer may be used to

decode the three channels of surround audio from the two

10   channels normally reserved for rear surround signals in a

conventionally compressed 5.1 channel digital audio surround

system.

In another aspect of the present invention, three or more

audio channels that may be geographically or sonically close to

15   each other may be exposed to multiple layers of compression and

decompression to record and present 6.1 or more channels of

surround audio using recording bandwidth of conventional 5.1

channel recording and recovery equipment.

In another aspect of the present invention 6.1 or more

20   discrete channels of an audio program may be encoded and

recorded to permit recovery of 5.1 or fewer channels of the

audio program using conventional equipment.

These and other features and advantages of this invention

will become further apparent from the detailed description and

25   accompanying figures that follow.  In the figures and

description, numerals indicate the various features of the

invention, like numerals referring to like features throughout

both the drawings and the description.


30              Brief Description of the Drawings

Fig. 1 is a block diagram of a 6.1 channel audio surround

system according to the present invention.

Fig. 2 is a is a block diagram of a conventional 5.1

channel audio surround system.

Fig. 3 is a diagram of a two parameter sound matrix.

Fig. 4 is a diagram of a 3-2 matrix encoder.

Fig. 5 is a diagram of a 2-3 matrix decoder.

Fig. 6 is a basic diagram of a 2-3 matrix decoder with
5    crosstalk cancellation.

Fig. 7 is a detailed diagram of a 2-3 matrix decoder with
dual detection crosstalk cancellation.

Fig. 8 is a simple block diagram of a 6.1 channel audio
surround system according to the present invention.

10    Fig. 9 is a simple block diagram of a 7.1 channel audio
encoder according to the present invention.

Fig. 10 is a simple block diagram of an 8.1 channel audio
encoder according to the present invention.

Fig. 11 is a simple block diagram of an audio encoding and
15    decoding system illustrating multiple signal lumping.

Fig. 12 is a simple block diagram of multi-phase encoding
and illustrating phase signal separation.

Fig. 13 is a simple block diagram of a four input encoder
with decorrelation.

20

Detailed Description of the Preferred Embodiment(s)

Referring to Fig. 1, multi-channel audio surround system 10
includes multi-channel encoding system 12 delivery means 14 and
multi-channel decoding system 16. Multi-channel encoding system
25    12 includes encoder block 18 and sound converters 22-28. Sound
sensors 22-28 may be conventional devices such as microphones or
other interface to sound source or generation device 32 and may
include signal processing capability. Encoder block 18 may also
include signal processing capability such as block 30 which may
30    include level adjustment as well as other signal processing

capability. In a currently preferred embodiment of the present
invention encoder block 18 of multi-channel encoding system 12
is a mirror image of decoder block 20 of multi-channel decoding
system 16 and may contain signal processing capability such as

5 block 34, other configurations may also produce satisfactory
results.

Sound information 36 encoded by encoder block 18 may be
recorded as sound signal 38 on a recording means 14 such as
Laser Disc 14A, CD 14B, DVD 14C, Film 14D, Magnetic Tape 14E, or

10 other media 14F or may be delivered in a transmitted signal such
as signal 14G. Signal 14G may be some form of electromagnetic
radiation such as conventional broadcast or satellite signals or
fiber optic light. Sound information 40 may be recovered from
recording means 14 and passed to decoder block 20. Decoder

15 block 20 may recover sound information 42 which corresponds to
the original sound information 36. sound information 42 may be
transformed to sounds 44-50 using any suitable device such as
speakers 51-57.

An alternative to coding extra "discrete" channels is to

20 encode additional channels into the existing tracks via
matrixing schemes. Matrix encoding employs mathematical
equations defining parameters for encoding transmission and
decoding of a plurality of signals encoded through two or more
transmitted tracks. The advantages of matrix approaches include

25 simplicity, bandwidth efficiency, and compatibility with
existing formats and playback sound systems.

Referring now to Fig. 3, one approach in multi-channel
audio coding uses amplitude 58 and phase 60 as two parameters in
the equations such as equation 66 describing output signals such

30 as output signal 68. The relative amplitude and relative phase
of signals 62 present in a plurality of audio tracks 64 can
represent several channels 66 comprised within one or more audio
tracks 64.

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Matrixing schemes are often described by the denomination A-B-C were A represents the number of input channels, B represents the number of actual recorded and transmitted channels, and C represents the number of output channels present

5    in the decode process. Thus, 3-2-3, 4-2-4, or 5-2-5, are some of the possible matrixing schemes possible using an amplitude-phase matrix approach such as illustrated in Fig. 3.

Fig.'s 4 and 5 show a basic 3-2-3 encoder/decoder system using encoder 78 and decoder 80 that could be used in

10   conjunction with the sound system shown in Fig. 3. Referring now to Fig. 4, Sl, signal 76, and Sr may be the Surround Left, Surround Back, and Surround Right signals respectively. Slt and Srt may be the Surround Left Total and Surround Right Total signals respectively. In the simple 3-2 encoding signal 76 is

15   reduced in level by 3 decibels in block 70 then added to Sl and Sr signals in adders 72 and 74 respectively to form the Slt and Srt. The 3 decibel attenuation to signal 76 afforded by block 70 preserves equal sound pressure levels for decoded and undecoded playback of the encoded signals Slt and Srt. Thus a

20   program recorded according to the present invention may be decoded and presented using a conventional audio system with minimal interference from the unused encoded signal 76. In a currently preferred embodiment of the present invention Slt and Srt are recorded in the track locations of Sl and Sr

25   respectively in a conventional 5.1 track sound format.

The .1 track represents a limited bandwidth low frequency effects channel that is treated as a discrete channel for encoding but only represents a fraction of the bandwidth required for other discrete channels. Hereinafter full

30   frequency channels will be referred to using whole decimal numbers and a limited bandwidth channel will be referred to as .1. Thus a system having four full frequency channels and a limited bandwidth channel will be referred to as 4.1.

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Referring now to Fig. 5, in decoder 80 Slt and Srt may be converted back to Sl, signal 76, and Sr through a summation of Slt and Srt in summer 82 to derive Sb, Sl and Sr.  Signal 76 is again reduced in level by 3 decibels at block 84 in order to

5    recover the original signal level of signal 76 applied to encoder 78.

The mathematical equations for the encode process of encoder 78 are:

$$Slt=Sl + 0.707(signal\ 76);$$

10

$$Srt=Sr + 0.707\ signal\ 76.$$

The mathematical equations for the decode process of decoder 80 are:

$$Sl=Slt;$$

$$signal\ 76 =0.707(Slt+Srt);$$

15

$$Sr=Srt.$$

Using a simple decoder such as decoder 80 the final separation between Sl, signal 76, and Sr may be only three decibels and may enable crosstalk to be detected.  Referring now to Fig. 6, use of a crosstalk cancellation stage such as

20   crosstalk cancellation block 86 as part of a decoder such as decoder 88 may be used to detect conditions of crosstalk in $Sl_n$, Rear signal $90_n$ and $Sr_n$ and actively remove the crosstalk signals from the offended channels such as in Sl, Rear signal 90 and Sr.

Referring now to Fig. 7, crosstalk cancellation decoder

25   such as crosstalk cancellation decoder 92 may include a duel detection network such as network 94 measuring Slt/Srt in stage 96 and measuring Slt+Srt/Slt-Srt in stage 98.  The result of the measurements of stages 96 and 98 may be used to controls voltage controlled amplifiers (VCA's) such as VCA 100 or equivalent

30   schemes, injecting subtractive crosstalk signals such as signals 102, 104 and 106 to the three output signals 108, 110 and 112 respectively.  The resulting separation of output signals such

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as output signals 108, 110 and 112 may be in excess of 20
decibels, and, through careful selection of the network time
constant Tc the action of the crosstalk cancellation scheme can
be made inaudible to listeners.

5    Application to Film Soundtracks

         Referring now to Fig. 8, the matrix techniques and 3-2-3
    schemes described Fig.'s 3-7 may be applied to a conventional
    audio surround system such as a 5.1 channel digital
    encoding/recording device such as device 114 and a 5.1 channel
10   digital playback device such as device 116 to achieve a 6.1
    channel format such as format 118 incorporating 6.1 discrete
    channels such as channels 122 and resulting in a full 6.1
    channel reproduction such as signals 120.  Left channel 122l,
    Center channel 122c, Right channel 122r and LFE (Low Frequency
15   Effects) channel 122x are fed directly into a 5.1 channel
    digital encoding/recording device such as device 114.  Surround
    signals such as Side Left channel 126, Rear channel 124, and
    Side Right channel 128 are first fed into an encoder such as
    matrix encoder 130.  Output 132 of matrix encoder 130 may then
20   be fed into conventional Surround Left and Surround Right inputs
    134 and 136 respectively.  Upon Playback the inverse order of
    operations may be used to extract 6.1 channels 120.

         Referring now to Fig.'s 9 and 10, multi-layer sound
    encoding according to the present invention may be applied to
25   encode and decode 7.1 and 8.1 discrete channels of surround
    audio.  Additional channels 140 or 148 may first be encoded with
    two conventional channels of input sound such as channels 142,
    via a first layer matrix encoder such as encoder 136 or 150
    respectively.  Output 144 of which may be recorded or otherwise
30   preserved using some media 146 such as on track Sl and track Sr
    of a film soundtrack.  To decode and playback program 152 the
    inverse order of operations 138 and 139 may be used to extract
    program 152, similarly for Fig. 10.

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This invention may also be applied to any conventional
audio surround system such as 7.1 channel formats, although the
text mainly makes reference to 5.1 formats, which are in more
common use.

5      Referring now to Fig. 11, a side-effect of matrixing can be
unwanted "lumping" or combining of multiple signals into one
channel.  Typically two equal signals such as signals 154 and
156 placed in two channels such as Sl and Sr separated by one
intermediate channel such as rear channel 158 may sum into the
10     intermediate channel resulting in large signal 160.  In this
condition Sl=Sr and rear channel 158=0, so in an encoder such as
encoder 162 where Slt=Sl+0.707(rear channel 158)=Sl and
Srt=Sr+0.707(rear channel 158)=Sr. Therefore Slt=Srt.  In a
decoder such as decoder 164, Sl=Slt and Sr=Srt and rear channel
15     158=0.707(Slt+Srt) assuming no crosstalk cancellation.

If crosstalk cancellation is present, and Slt=Srt, a
crosstalk cancellation detector analysis may detect applied
signals 166 as being of the condition Slt/Srt=1 and Slt+Srt/Slt-
Srt=max.  Thus crosstalk cancellation present in decoder 164
20     will thus add crosstalk signals to Sl and Sr that are the
opposite cardinal point of the offending signals, and after the
crosstalk cancellation subtractive stage the outputs will be:
Sl=Slt-Srt=0; Sr=Srt-Slt=0; Sb=0.707
(Slt+Srt)=1.414Slt=1.414Srt.  Output 168 may be characterized as
25     only a Rear signal such as large signal 160 at the output of the
Encode/Decoder process, when equal signals were originally
placed into Side Left and Side Right inputs.

Referring now to Fig. 12, a solution to this "lumping"
issue is to add a function such as blocks 170 and 174 in encoder
30     172 to selectively alter the phase relationships between two
equal signals such as signals 176 and 178. This would result in
the two signals being reproduced at output 180 as spread out
over the three adjacent channels such as channels 181-183

instead of lumping into channel 182 as demonstrated in Fig. 11.
A crosstalk cancellation scheme such as discussed in Fig. 7
would not activate since no clear cardinal amplitude or phase
relationships exist between the Slt and Srt signals. Cardinal
5   points would have been one of the below conditions: Slt=Srt, or
Slt=-Srt, or Slt=1 and Srt=0, or Slt=0 and Srt=1.

There are several possible means for altering the phase
relationships as mentioned here. These include All-Pass filter
networks, Hilbert Transform functions, Time-domain signal
10  distribution, and pitch shifting. Such schemes have been
referred to as Decorrelation in the Holman Patent 5,043,970.

A 3-2-3 encoder/decoder block diagram as shown in Fig. 12
presents a three input solution. Signals placed equally in
inputs Side-Left and Side-Right would have their relative phase
15  altered and would thus be decoded as spread across S-L, Rear,
and S-R.

Referring now to Fig. 13, a 4-2 encoder block diagram with
4 inputs 184 is shown. Signals such as signals 185-187 applied
to inputs Sl, Rear or Sr would be encoded and decoded as
20  appropriate. A signal such as signal 188 applied to a Surround-
All input such as input 190 would be decoded as spread across
the outputs 192.

Other applications of the Invention:

Multichannel Digital Film Soundtracks transferred to Home
25  Video media, such as DVD 14c (Digital Versatile Disc) or
Laserdisc 14a with Dolby Digital track, can benefit from this
invention. The listener at home would simply need a matrix
decoding device such as multi-channel decoding system 16, either
as an add-on to an existing multichannel surround sound system,
30  or built-in to a new Surround sound processor, in order to
extract the additional channels. Similarly, broadcast media 146

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with multichannel digital sound, such as Direct Satellite (DSS) or the new Digital TV standard, can benefit from the invention.

Multichannel music, recorded onto 5.1 channel formats can also benefit from the invention through added encoded channels

5   to be decoded in the home, much the same way as for audio-visual media.

Having now described the invention in accordance with the requirements of the patent statutes, those skilled in this art will understand how to make changes and modifications in the

10  present invention to meet their specific requirements or conditions. Such changes and modifications may be made without departing from the scope and spirit of the invention as set forth in the following claims.

●                           ●

12

I claim:

1. A multi-channel audio system, comprising:

a secondary encoding means for encoding three or more secondary signals into two or more secondary channels;

a primary encoding means for encoding 3.1 or more primary

5    signals and said two or more secondary channels together into a total encoded program signal;

means for recording said total encoded program signal as a' recorded signal;

a primary decoder means for decoding said recorded signal

10   into 3.1 or more primary output signals and two or more secondary channels; and

a secondary decoder means for decoding said two or more secondary channels into three or more secondary output signals.

2. A multi-channel audio encoding system, comprising:

a secondary encoding means for encoding three or more secondary signals into two or more secondary channels; and

a primary encoding means for encoding 3.1 or more primary

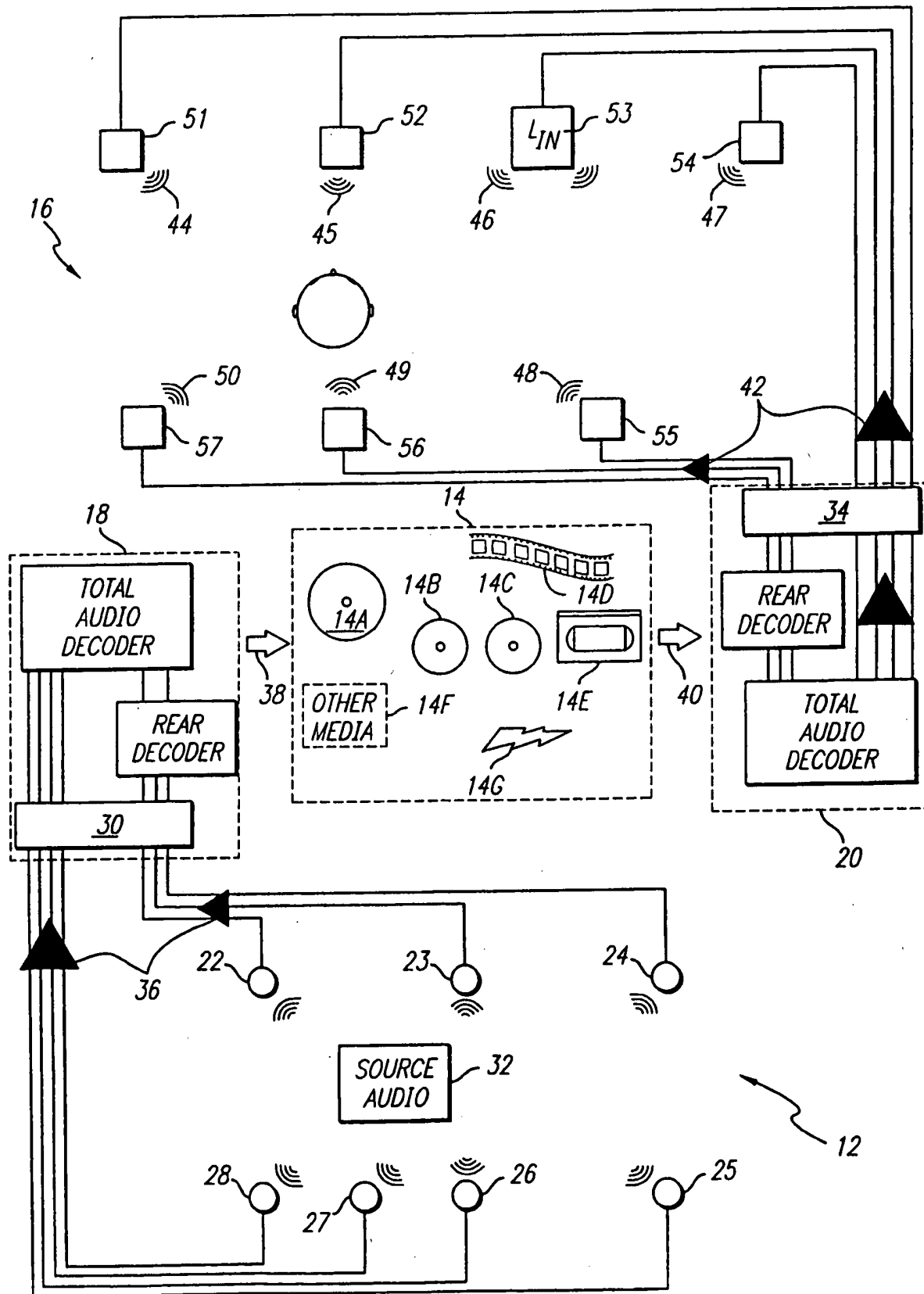5    signals and said two or more secondary channels together into a total encoded program signal.

3. A multi-channel audio decoding system, comprising:

a primary decoder means for decoding a multi-channel audio signal into 3.1 or more primary output signals and two secondary channels; and

5    a secondary decoder means for decoding said two secondary channels into three or more secondary output signals.

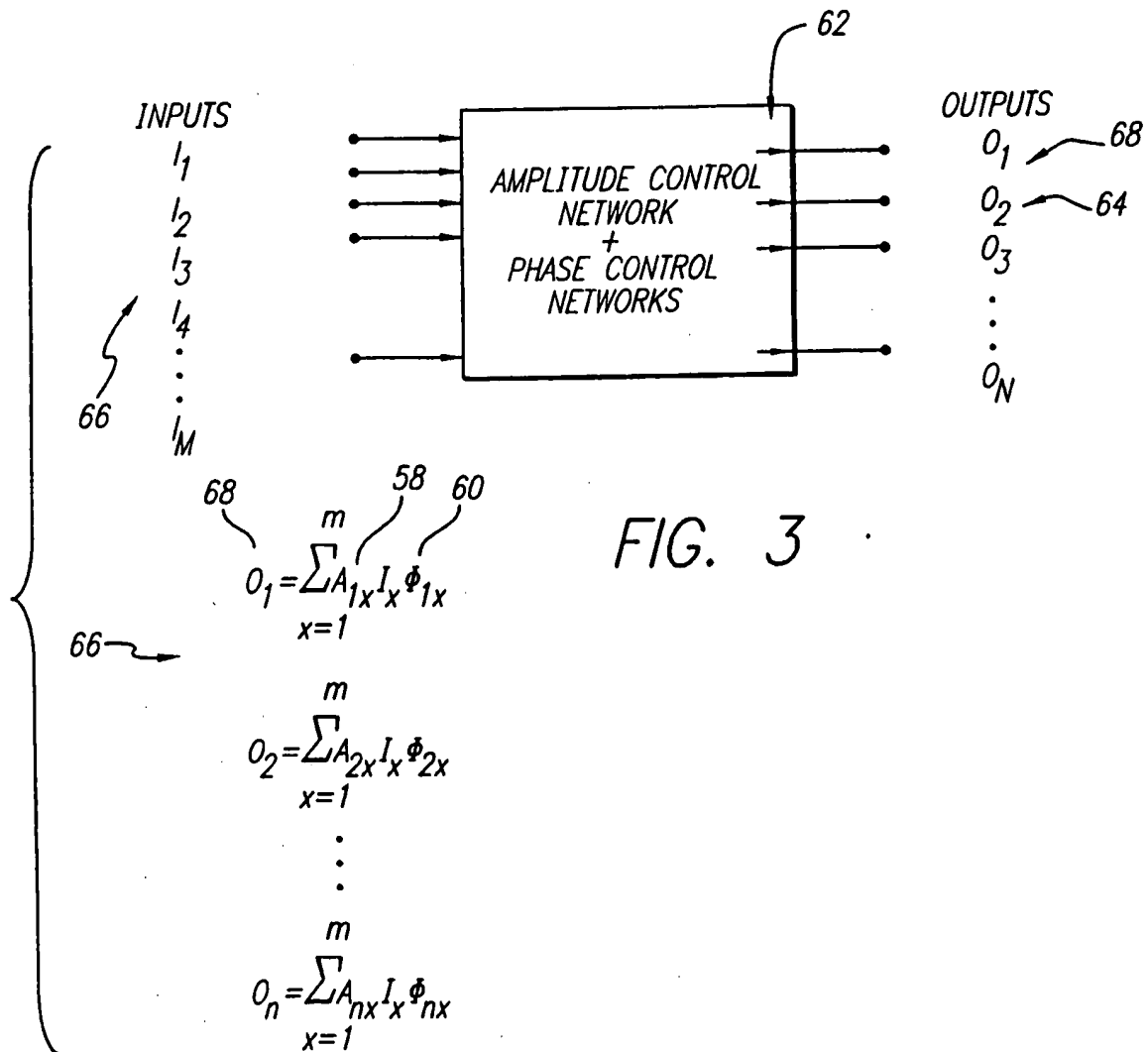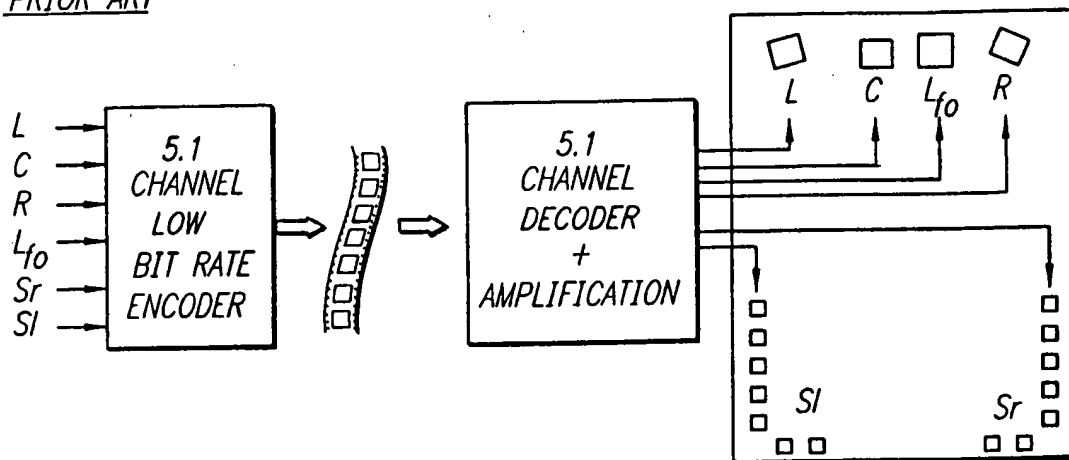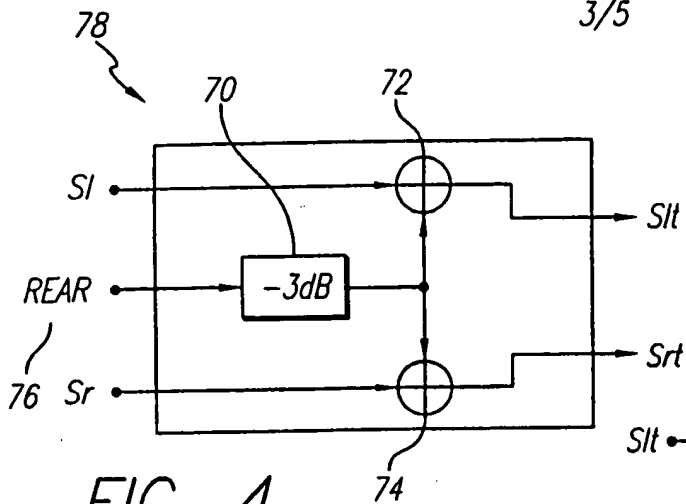*FIG. 1*

# FIG. 2
### PRIOR ART



# FIG. 3



$$O_1 = \sum_{x=1}^{m} A_{1x} I_x \phi_{1x}$$

$$O_2 = \sum_{x=1}^{m} A_{2x} I_x \phi_{2x}$$

$$O_n = \sum_{x=1}^{m} A_{nx} I_x \phi_{nx}$$

*78*

SI •

REAR •

*76* Sr •

*70*

*72*

−3dB

*74*

→ Slt

→ Srt

## FIG. 4
### PRIOR ART

*80*

Slt •

Srt •

*82*

−3dB

*84*

→ Sl

→ REAR

→ Sr

## FIG. 5
### PRIOR ART

*76*

*85*

$S_{IN}$

Slt •

Srt •

−3dB

90N

*86*
CROSSTALK
CANCELLATION
NETWORK

→ Sl

→ REAR

→ Sr

*90*

$S_{RN}$

## FIG. 6 PRIOR ART

*94*

*112*

Slt •

Srt •

*96*

DETECTOR 1

DETECTOR 2

Tc

DETECTOR 3

DETECTOR 4

Tc

VCA NETWORK

*106*

*104*

*102*

*100*

*98*

+

−

*92*

→ REAR

*110*
→ Sl

→ Sr

*108*
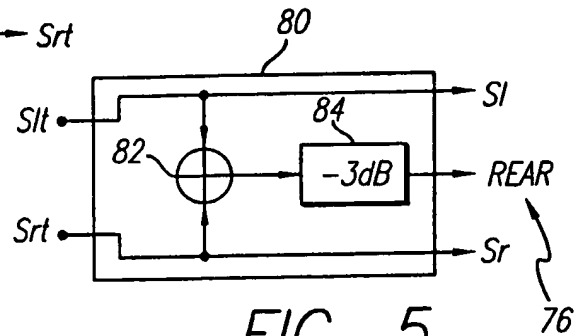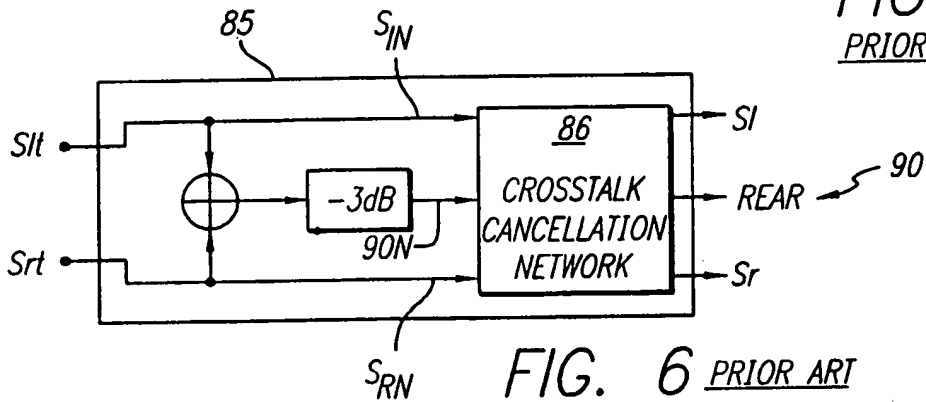
## FIG. 7
### PRIOR ART
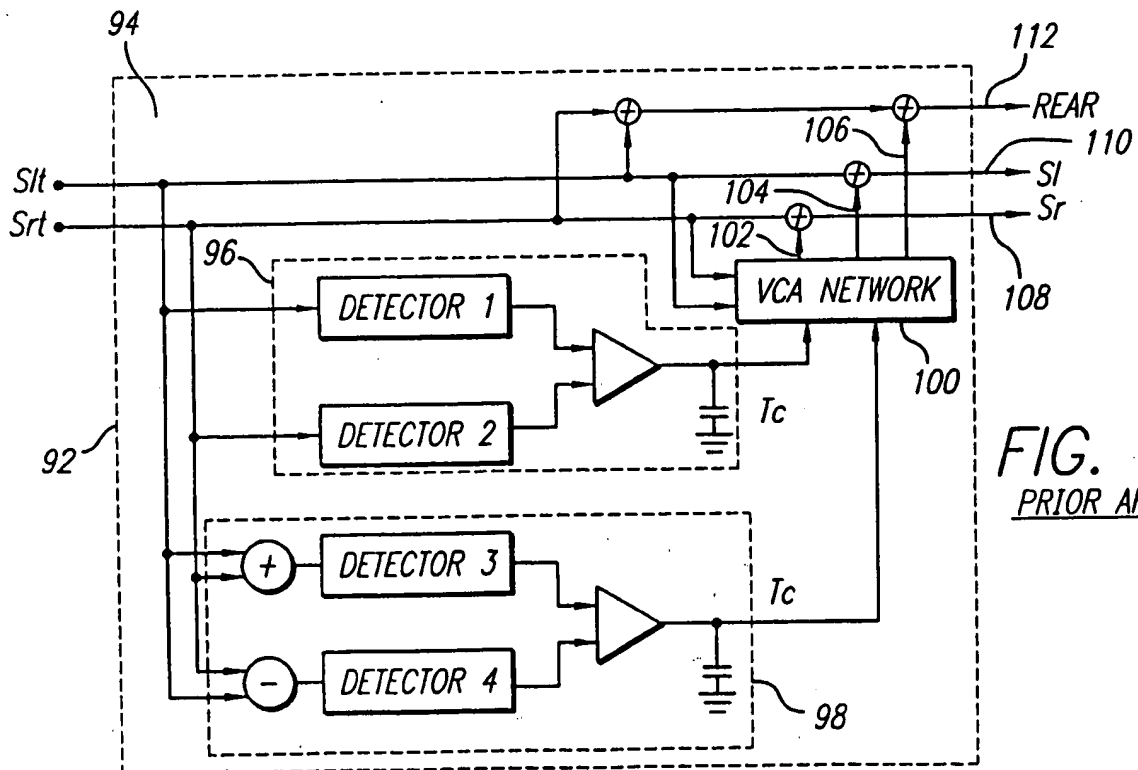
**SUBSTITUTE SHEET (RULE 26)**

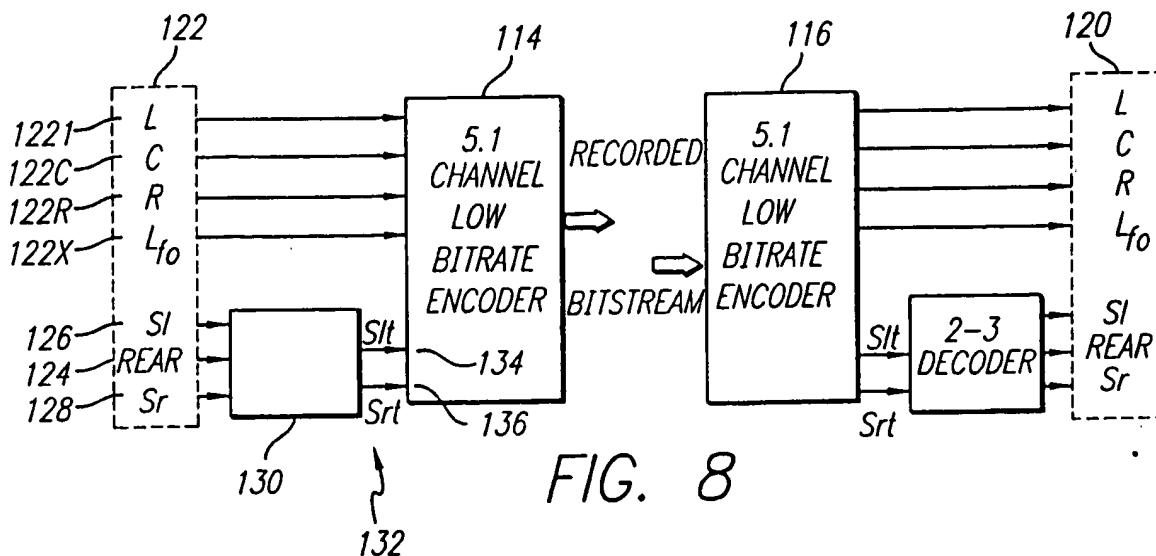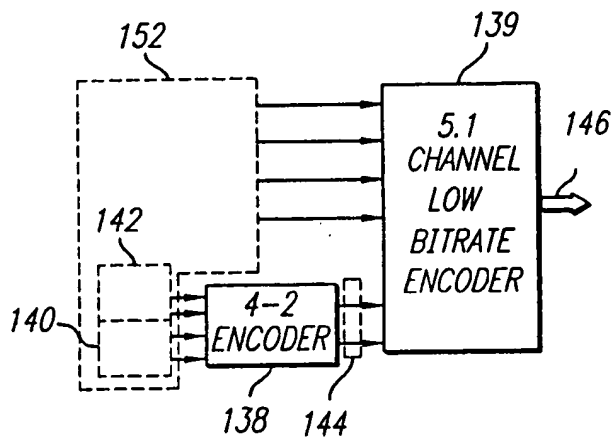FIG. 8



FIG. 9


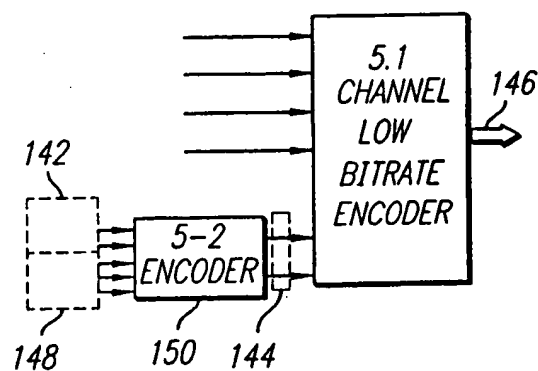
FIG. 10
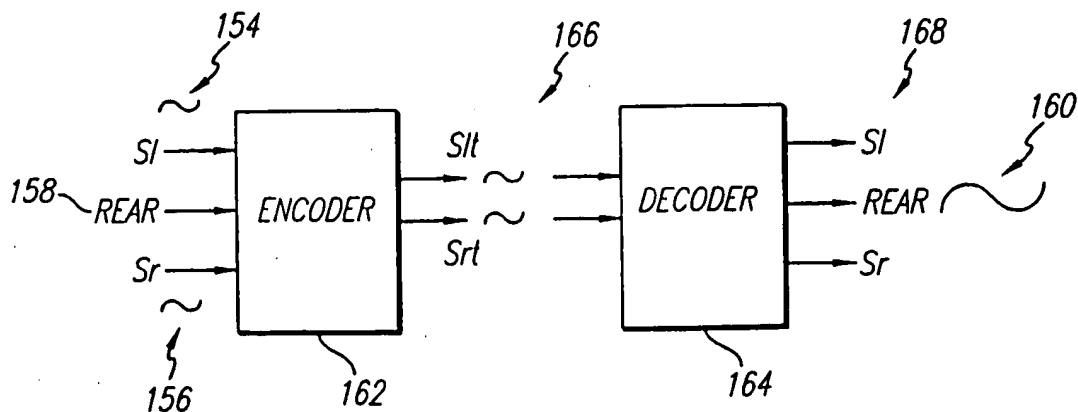


FIG. 11
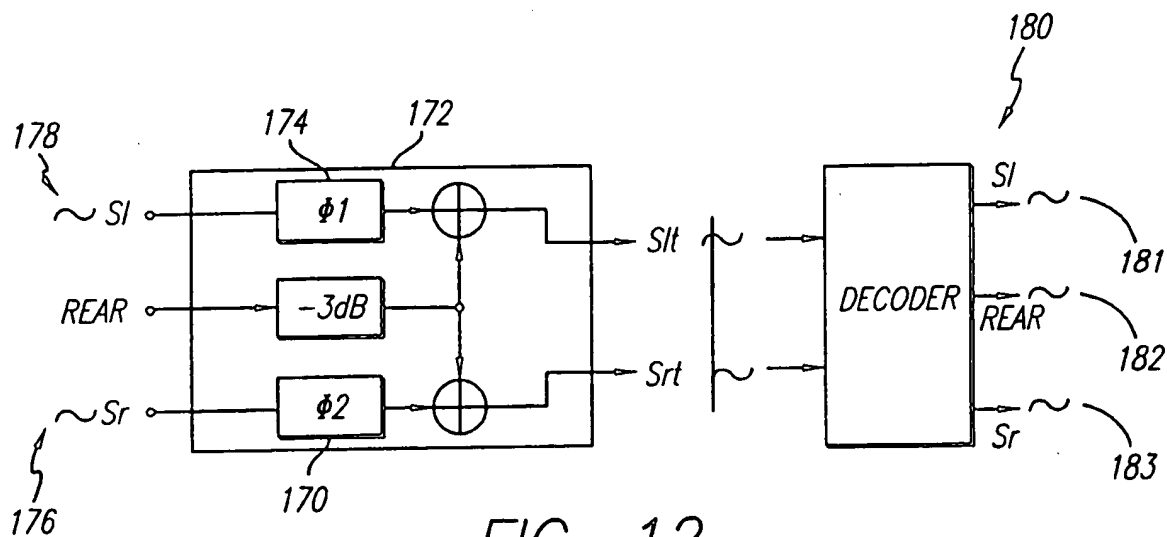
FIG. 12
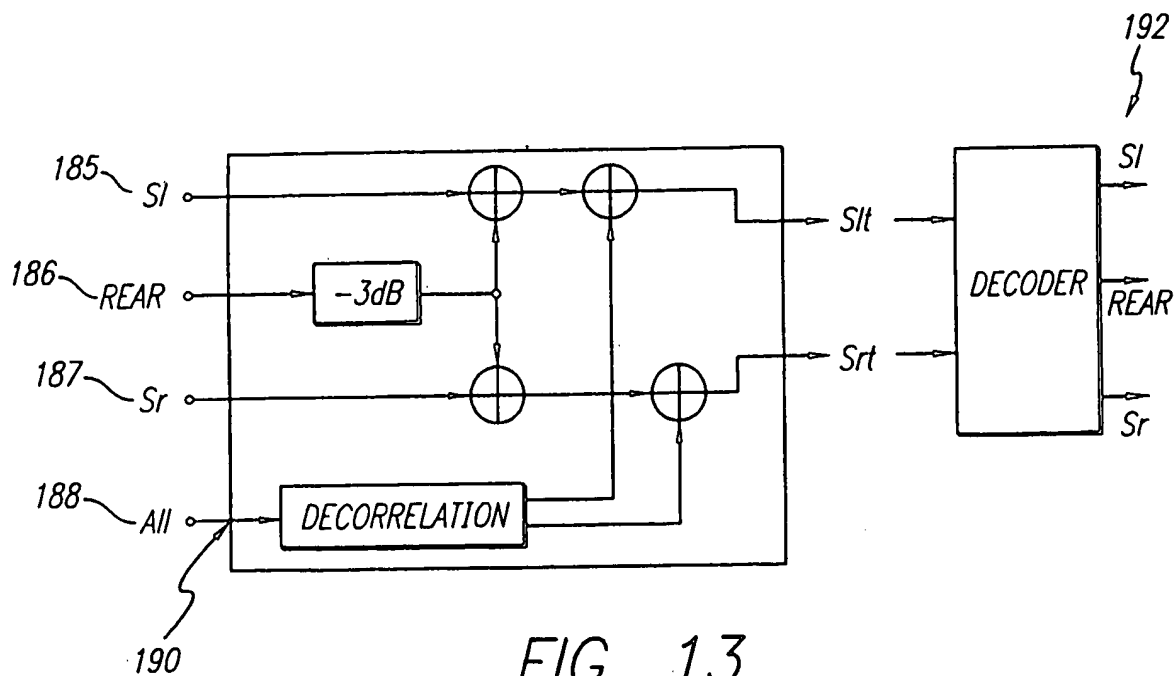


FIG. 13

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# INTERNATIONAL SEARCH REPORT

## A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04S3/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   H04S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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| X | US 5 701 346 A (HERRE ET AL.) 23 December 1997 (1997-12-23) column 1, line 6-13 column 2, line 23-59 column 3, line 32-59 column 4, line 33 -column 7, line 2 --- | 1-3 |
| A | EP 0 119 101 A (DOLBY LABORATORIES) 19 September 1984 (1984-09-19) page 17, line 21 -page 22, line 11 --- | 1-3 |

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[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 20 December 1999 | 12/01/2000 |

| Name and mailing address of the ISA | Authorized officer |
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| European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016 | Zanti, P |

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